DOCUMENT RESUME

ED 437 219 PS 028 225

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TITLE Intersensory Redundancy and Seven-Month-Old Infants' Memory for Arbitrary Syllable-Object Relations.
SPONS AGENCY Delaware Univ., Newark.; National Inst. of Child Health and Human Development (NIH), Bethesda, MD.
PUB DATE 1999-04-00
NOTE 21p.; Paper presented at the Biennial Meeting of the Society for Research in Child Development (Albuquerque, NM, April 15-18, 1999).
PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Association (Psychology); Child Language; Habituation; Infant Behavior; *Infants; Language Acquisition; Learning Processes; *Memory; *Redundancy; Retention (Psychology); Sensory Integration; *Syllables
IDENTIFIERS Synchrony; Vocalization

ABSTRACT

Seven-month-old infants require redundant information such as temporal synchrony to learn arbitrary syllable-object relations. Infants learned the relations between spoken syllables, /a/ and /i/, and two moving objects only when temporal synchrony was present during habituation. Two experiments examined infants' memory for these relations. In Experiment 1, infants remembered the syllable-object relations after 10 minutes, only when temporal synchrony between the vocalizations and moving objects was provided during learning. In Experiment 2, seven-month-olds were habituated to the same syllable-object pairs in the presence of temporal synchrony and tested for memory after 4 days. Once again, infants learned and showed emerging memory for the syllable-object relations 4 days after original learning. These findings are consistent with the view that prior to symbolic development infants learn and remember word-object relations by perceiving redundant information in the vocal and gestural communication of adults. (Contains 29 references.) (Author)

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Intersensory Redundancy and Seven-Month-Old Infants' Memory for Arbitrary Syllable-Object Relations

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We thank R. Golinkoff for her useful comments on previous drafts. The writing of this paper was supported by a General University Research Grant from the University of Delaware to L.J.G. and an NICHHD grant to L.E.B. These data were presented at the April 1999 Biennial Meeting of the Society for Research in Child Development, Albuquerque, NM. Address correspondence to Lakshmi J. Gogate, Psychiatry, Box 1203, SUNY at Brooklyn, Brooklyn, NY 11203, E-mail: lgogate@netmail.HSCBKLYN.edu, phone: (718) 270-4140, fax: (718) 270-3910.

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Intersensory Redundancy

and

7-Month-Old Infants' Memory for Arbitrary Syllable-Object Relations

Abstract

Seven-month-old infants require redundant information such as temporal synchrony to learn arbitrary syllable-object relations (Gogate & Bahrick, 1998). Infants learned the relations between two spoken syllables, /a/ and /i/, and two moving objects only when temporal synchrony was present during habituation. Here we present two experiments to address infants' memory for these relations. In Experiment 1, infants remembered the syllable-object relations after 10 min, only when temporal synchrony between the vocalizations and moving objects was provided during learning. In Experiment 2, 7-month-olds were habituated to the same syllable-object pairs in the presence of temporal synchrony and tested for memory after 4 days. Once again, infants learned and showed emerging memory for the syllable-object relations, 4 days after original learning. These findings are consistent with the view that prior to symbolic development infants learn and remember word-object relations by perceiving redundant information in the vocal and gestural communication of adults.

Infants remember visual events for a long period of time. For example, 3-month-olds remember the motions of objects 12 weeks following familiarization to visual displays (Bahrick & Pickens, 1995). 5½-month-olds remember the activities that people perform 7 weeks following familiarization to dynamic video-displays (Bahrick, Gogate, & Ruiz, submitted). Studies have also shown that 2-month-olds remember extended speech (nursery rhymes) three days following familiarization (Spence, 1996), and 7½-month-olds remember words from a passage they heard two weeks earlier (Jusczyk & Hohne, 1997). However, no studies have shown whether preverbal infants remember the relations between what they see and hear, such as objects and words. Learning and remembering these relations can facilitate the discovery of word meaning and are precursors to lexical comprehension. However, the perceptual and memory processes underlying word-to-object mapping during the first year have not been investigated. Because of the paucity of investigations, the domain of early word comprehension has been called the "black hole" of language development (Golinkoff & Hirsh-Pasek, 1998).

How do infants relate words and objects from ongoing communication? Words are arbitrarily related to objects through convention, and are learned through sensory experience. For example, an infant can relate the word ball with the object 'ball' by hearing the word and seeing the object. Some researchers have hypothesized that infants map words onto existing representations of objects (Stemmer, 1989), or associate words and objects (Stager & Werker, 1997; Werker, Cohen, Lloyd, Casasola et al., 1998) or concepts (Jusczyk & Hohne, 1997). It is our view that young infants relate words and objects by detecting intersensory redundancy (also see Bates, 1993; Sullivan & Horowitz, 1983; Zukow-Goldring, 1997). Infants' perceptual-system is integrated from the start and becomes differentiated with development (Gibson, 1969). Thus, infants may use integrated, redundant, or global information across the senses to detect arbitrary

relations in multimodal events (Bahrick & Pickens, 1994). Redundant information includes temporal synchrony, shared rhythm, tempo, and intensity shifts. This type of redundancy is available in the sound and sight of a talking person. The movements of the mouth and lips are synchronous with the speech sounds. The redundancy specifies that the sound and sight belong together (Bahrick & Lickliter, in press), and sets the stage for further processing of auditory-visual relations, including arbitrary relations.

Recently, Gogate and Bahrick (1998) demonstrated that infants rely on intersensory redundancy to learn arbitrary syllable-object relations. In an infant-controlled habituation procedure, infants received two alternating video-displays of the syllables, /a/ and /i/, paired with a toy porcupine and a crab, or a lamb chop and a star in one of three conditions. (A) The syllables were vocalized in synchrony with moving objects (moving-synchronous condition), or (B) they were vocalized out of phase with the movements of the objects (moving-asynchronous condition), or (C) they were vocalized when the objects were static (still condition). Infants' learning of the syllable-object relations was tested using a modified 'switch method' (Bahrick, 1992; 1994; Stager & Werker, 1997; Younger & Cohen, 1983 for arbitrary relations between visual attributes) where the relation between the objects and syllables was switched or mismatched. Results indicated that only the infants in the moving-synchronous condition looked longer to the switch trials than to the no change trials (Fig.1). Because the only difference between habituation and switch trials was the change in syllable-object relations, infants' longer looking in this condition indicated detection of the switch in the objects' relation to the syllables. Thus, at 7 months, infants use redundancy (temporal synchrony) between spoken syllables and objects' motions to learn arbitrary syllable-object relations. In contrast, research has demonstrated learning of syllable-object relations in the absence of temporal synchrony only by the age of 14 months (Werker et al., 1998). Thus, intersensory redundancy serves to highlight the connection between vocalizations and objects, specifying the link between referent and object

and providing one of the earliest bases for learning and memory for these relations. Research has also demonstrated that mothers provide a great deal of temporal synchrony and spatial co-location between words and objects when they teach the names for novel objects and actions to their 5- to 8-month-old infants (Gogate, Bahrick, & Watson, in press). As infants develop language and no longer need synchrony to highlight word-referent relations, but can detect these relations on their own, mothers' use of synchrony decreases and naming in the presence of static objects increases. Thus, intersensory redundancy is provided when it is most needed and can serve as a vehicle for the early detection of word-referent relations. This, in turn, allows infants to further differentiate, relate, and remember arbitrarily paired words and objects.

The proposed process of differentiation differs from and complements the process of association proposed by Birch and Lefford (1963) in many ways. First, it provides an explanation for why and when some concurrent sounds and objects are perceived as related and others are not. Accordingly, it proposes a developmental progression where early detection of redundant information such as synchrony facilitates eventual differentiation of embedded arbitrary relations. Intersensory redundancy can be perceived by detecting invariant relations with a unified perceptual system through the process of differentiation, and requires little specific learning (e.g., Bahrick & Lickliter, in press; Gibson, 1969). In contrast, arbitrary relations must be learned through experience by relating information across two sense modalities that share no intrinsically similar properties. Thus, intersensory redundancy can be considered a special kind of co-occurrence where the same information occurs in two modalities simultaneously. Detection of this redundancy organizes early perceptual development, allows infants to detect that objects and sounds belong together, and eventually enables infants to relate meaningful modality-specific components. In this way differentiation and association can be seen as complementary processes.

Lexical development also entails memory for word-referent relations. When an adult

names an object from an array of objects and events, infants' memory for a specific word-object relation can facilitate lexical-comprehension. Thus, in addition to merely detecting the mismatch between words and objects, infants must search for the correct objects when given the words. Under what learning conditions do infants remember word-object relations, and does memory last across a period of days? To address these questions we conducted two experiments. Experiment 1 tested the infants who participated in Gogate and Bahrick's (1998) study in a follow-up intermodal preference procedure. Researchers have used several versions of this method to study older infants' word-to-object mapping (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987; Schafer & Plunkett, 1998). Upon hearing a word, infants were expected to search for and look first at the matching object from two choices. Because learning occurred only in the moving-synchronous condition of Gogate and Bahrick's study (1998), those infants alone were expected to remember the relations 10-min later. Alternatively, different conditions could have resulted in different levels of learning. Thus, in the asynchronous or still condition, although infants did not look longer to the switched displays after habituation, lower levels of learning of the syllable-object relations might result in familiarity and matching on the memory test. Therefore, we tested infants' memory for these relations under the three conditions. Experiment 2 tested a different group of infants to determine if memory lasted for a longer period.

Experiment 1

Method

Participants. The forty-eight 7-month-old infants (M = 220 days, SD = 5.14) who had completed Gogate and Bahrick's (1998) experiment participated. These full-term, healthy infants were recruited from the local birth records. Their parents were middle class, with 12 or more years of education. Infants were required to complete at least 8 of 12 trials to be included in the final sample. Two participants in the moving-synchronous condition did not meet this criterion

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due to excessive fussiness. Thus, the final sample consisted of 14 infants in the moving-synchronous condition and 16 infants each in the moving-asynchronous and still conditions.

Stimuli. The video-displays consisted of a plastic crab and a porcupine, or a plastic lamb chop and a wooden star, each paired with /a/ or /i/, in one of three conditions (identical to Gogate & Bahrick, 1998). Infants easily distinguish these syllables (Kuhl & Meltzoff, 1988). A female actor (not visible on the videos) uttered the syllables in infant-directed speech to resemble isolated monosyllabic words. The rhythm, tempo (26 tokens/min), and intonation patterns of the syllables were controlled across conditions.

For the moving-synchronous display, each object was moved in synchrony with each syllable. The hand-held objects were randomly moved forward and back or laterally as if show them to the infant. The mean time lag between syllable-onset and object motion was .45 s (SD = .19), and syllable-offset and object motion was .04 s (SD = .11) across 20 random occurrences. For the moving-asynchronous condition, each object was moved out of synchrony with each syllable. The mean time lag between syllable-onset and object motion was .82 s (SD = .68), and syllable-offset and object motion was .90 s (SD = .86) across 20 random occurrences. For the still condition each object was static and accompanied by a syllable.

Procedure and apparatus. Following habituation under a moving-synchronous, moving-asynchronous, or still condition (Gogate & Bahrick, 1998) and a 10 min-delay (indicated by a timer) infants were brought from the waiting room to the testing room for the two-choice intermodal memory test. Infants were seated 55 cm away and equidistant from two adjacent 20" color monitors (Sony KV20M10). They received two identical blocks of six 15-s trials under their prior habituation condition (moving-synchronous, asynchronous or still). On each trial, infants heard a series of /a/ or /i/ from a central speaker, and watched side-by-side displays of the two distinctive objects. Infants' attention was centered before each trial using bells located between the monitors. For the moving-synchronous test, the two objects were played moving in

synchrony with one another and in synchrony with each syllable. For the moving-asynchronous test, the two objects moved out of synchrony with one another and the two syllables. For the still test, the objects were static while the each syllable was presented. On each trial, /a/ or /i/ occurred twice (approximately 4 s) before the objects appeared on the monitors. When the objects appeared, infants were expected to search for and select the matching display if they remembered the syllable-object relations learned during the prior habituation procedure. The lateral positions of the displays were counterbalanced across the two blocks. The order of syllable presentation was randomized but identical across blocks.

Trained observers, blind to the lateral positions of the displays, recorded infants' looks to the displays from one of two peepholes situated behind the monitors. The mean proportions of first looks (PFL) to the matching object-display were measured. PFLs were obtained by dividing the number of trials where infants looked first to the matching display by the total number of trials. The mean correlation between two observers' PFLs calculated for 16 infants (33%) was .91 (SD = .09).

Results and Discussion

Infants in the moving-synchronous condition alone remembered the syllable-object relations. An analysis of variance of the PFLs across the two blocks of trials by condition (3) was significant, $F(2, 43) = 4.45$, $p < .02$ [1]. Multiple comparison t-tests (Scheffe's two-tailed $p < .05$) revealed that, infants in the moving-synchronous condition looked first to the matching object-displays more often than infants in the still or moving-asynchronous condition (Fig 2, Expt 1). Infants showed no stimulus or right or left side bias within condition [$ps > .1$].

Further, we compared individual participants' success in syllable-object matching (PFLs above and below 50% treated as a dichotomous variable) across conditions. Infants in the moving-synchronous condition (10 out of 14) looked first to the matching object-displays more

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often than in the asynchronous (4 out of 16; pooled $z = 2.54$, $p = .006$), or still condition (6 out of 16; pooled $z = 1.86$, $p = .03$).

In summary, given intersensory redundancy during learning, 7-month-olds remembered the arbitrary syllable-object relations 10-min later. Because infants heard the syllables 4 s prior to viewing the now familiar object-displays, they oriented to the matching display first. These results are consistent with prior findings, showing fast mapping of familiar words and objects by 15- and 24-month-olds (Fernald, Pinto, Swingley, Weinberg, et al., 1998). Given these results, we conducted a second experiment to test whether infants would remember the syllable-object relations longer (4 days) if temporal synchrony were provided during learning.

Experiment 2

Method

Participants. Sixteen 7-month-olds ($M = 220$ days, SD, 3.11 days), 8 males and 8 females participated in two visits. The recruitment criteria were identical to that of Experiment 1. Eight additional infants were excluded from the final sample due to experimenter error ($N = 1$), equipment failure ($N = 1$), fatigue ($N = 1$), external interference ($N = 3$), and failure to return for the second visit ($N = 2$).

Procedure and apparatus. On the first visit, infants were habituated and tested under the moving-synchronous condition of Gogate and Bahrick's earlier study (1998). Infants were seated in an infant seat facing a TV monitor. Two syllable-object displays were played one at a time on the monitor from one of two VCRs (Panasonic AG 7750). Infants received the alternating displays until their looking on two consecutive trials was less than 50% of their looking on the two initial trials. Next (after two post-habituation trials to control for regression effects), they received the two no change and two switch test trials counterbalanced for order. Infants controlled the length of each trial. A trial began when infants fixated on the monitor and ended

when they looked away for 1.5 s or longer. Trained observers, blind to the condition, recorded infants' looking to the displays (sec.). The mean correlation between two observers' scores for 6 out of 16 subjects (37.5%) was .97 (SD = .03). The infants returned after a mean interval of 4 days (range, 2-7 days; SD, 2 days) for the second visit, and received the memory test identical to the moving-synchronous condition of Experiment 1. The mean correlation between two observers' proportions of first looks to the matching display (PFL) calculated for 7 out of 16 infants (44%) was .91 (SD = .02).

Results and Discussion

A mixed-analysis of variance assessed infants' looking (sec) as a function of trial type (switch, no change), type of syllable-object pairing (4), and order of presentation of trial type (2). The analysis revealed a significant effect of trial type ($F(1, 8) = 6.5$, $p = .034$), but not of syllable-object pairing ($F(3, 8) = .70$, $p > .1$), order of test presentation ($F(1, 8) = .25$, $p > .1$), or interactions between factors (ps > .1). These results replicate those of Gogate and Bahrick (1998). Infants looked significantly longer to the switch trials than to the no change trials [Fig. 1, Expt. 2], indicating that they learned the syllable-object relations after habituation to temporally synchronous events. A paired t-test comparing infants' looking to the first versus the second switch trial showed no significant difference ($M = .32$ s, $t(15) = .07$, $p > .1$). Thus, infants attended to the redundant information and arbitrary relations across both syllable-object pairs. An analysis of individual participants' scores revealed that 11 of the 16 infants looked longer to the switch than to the no change trials.

On the memory test 4 days later, infants looked first more often than chance (50%) to the matching object display across the two blocks of trials [$M = .56$, $t(15) = 2.57$, $p < .025$; Fig. 2, Expt. 2]. Secondary analysis of the PFLs revealed no visual preference for the right or left position of display, or a stimulus bias, or a difference between blocks (ps > .1). These group

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results show that temporal synchrony facilitated long-term memory for syllable-object relations. An analysis of individual participants' PFLs revealed, however, that 10 of the16 infants looked first to the syllable-matched object more often than chance (50%), suggesting emergent memory for syllable-object relations. Infants' PFLs and their retention interval were not correlated (Pearson r = -.40, p = .12).

General Discussion

The results of experiments 1 and 2 demonstrate that 7-month-old infants remember arbitrary syllable-object relations 10 min. and 4 days after the original learning occurred under the moving-synchronous condition. They showed evidence of memory by looking first to the matching object upon hearing a syllable in a two-choice intermodal procedure. This extended retention is particularly impressive given that infants received only a relatively brief exposure to the two syllable-object displays, (Expt. 2, M =154.76 s, SD = 81.12). These findings demonstrate that preverbal infants have important requisite capabilities that provide a basis for lexical development and the eventual understanding of word meaning. The infants remembered the relations by selectively attending to and perceiving the redundant information between an utterance and a moving object.

The present findings with 7-month-olds also provide the earliest evidence for learning of and memory for arbitrary syllable-object relations. As young as 7 months, infants have the capability for recognizing recently learned syllable-object relations as long as 4 days later, providing a basis for the development of a referential system. Prior to symbolic-lexical development, infants detect and remember word-object relations by detecting intersensory redundancy between the syllables and movements of the objects provided by adults. Redundancy such as temporal synchrony appears to orient infants to the relationship between the spoken word and the object referent at a time when infants do not yet know that words go with or stand for

objects. Abstraction of these relations typically emerges in a social context and temporal synchrony between word and gesture is prevalent in natural communication. Further, mothers use it to teach their preverbal infants word-referent relations (Gogate et al., in press). The temporal coordination between vocalization and gesture provided by adults appears to be important for specifying which words and objects go together, and may provide an important basis for early word learning, memory, and comprehension (Gogate, Walker-Andrews, & Bahrick, in press).

Footnote

1. The PTLTs and longest looks to the matching displays were also calculated across blocks. These measures did not differ by condition (ps > .1).

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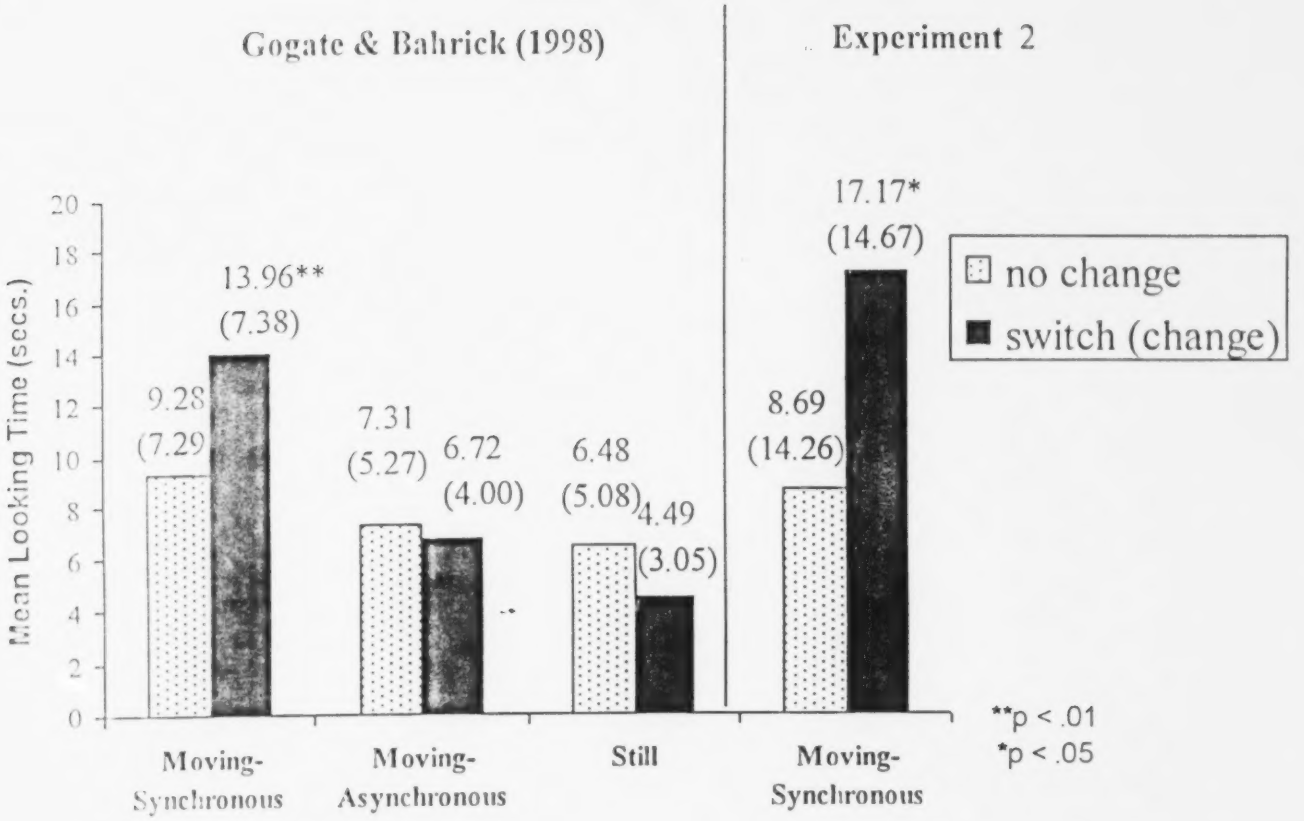
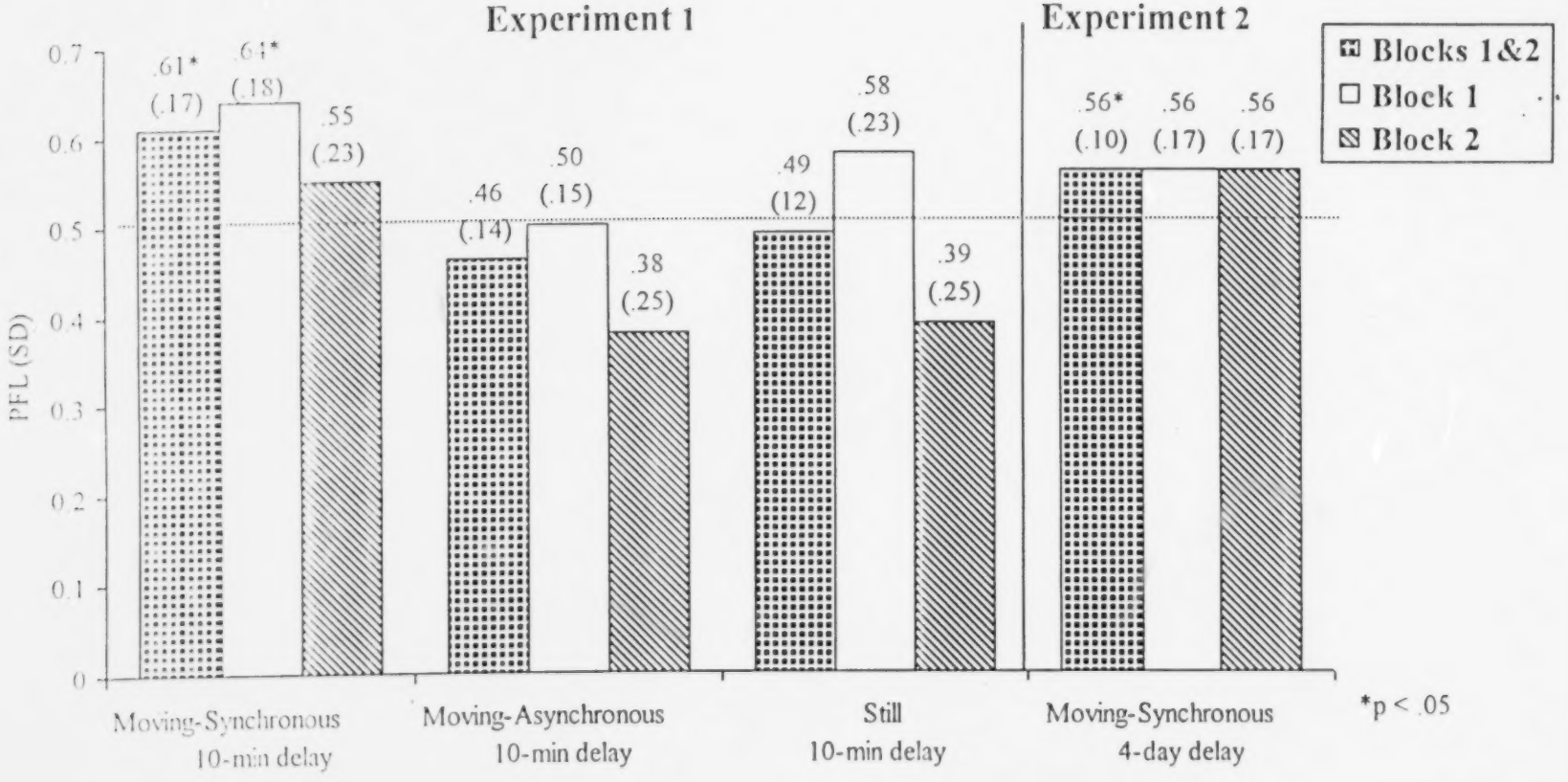
Figure Captions

Fig 1. Mean looking (and SDs) to syllable-object pairs following habituation under the moving-synchronous, moving-asynchronous, and still conditions as a function of trial type.

Fig 2. Proportion of first looks (and SDs) to the syllable-matched display (PFL) on the intermodal memory tests under the moving synchronous, moving-asynchronous, and still conditions.


Gogate & Bahrick (1998)
Experiment 2
Mean Looking Time (secs.)
20
18
16
14
12
10
8
6
4
2
0
9.28
(7.29)
13.96**
(7.38)
7.31
(5.27)
6.72
(4.00)
6.48
(5.08)
4.49
(3.05)
8.69
(14.26)
17.17*
(14.67)
no change
switch (change)
**p < .01
*p < .05
Moving-
Synchronous
Moving-
Asynchronous
Still
Moving-
Synchronous


Experiment 1
Experiment 2
Blocks 1&2
Block 1
Block 2
PFL (SD)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
.61* (.17)
.64* (.18)
.55 (.23)
.46 (.14)
.50 (.15)
.38 (.25)
.49 (12)
.58 (.23)
.39 (.25)
.56* (.10)
.56 (.17)
.56 (.17)
Moving-Synchronous 10-min delay
Moving-Asynchronous 10-min delay
Still 10-min delay
Moving-Synchronous 4-day delay
*p < .05